The
British Carbon Group

Carbon Newsletter

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2017 Ubbelohde lecturer

SCI

ROYAL SOCIETY OF CHEMISTRY

IOP Institute of Physics

Editorial

The whole carbon community must feel a sense of loss and sadness at the passing of Harry Kroto. Many in the British Carbon Group knew him not only as an inspiring scientific leader and researcher but as a friend. In this issue of this newsletter we are including a number of personal tributes and memories. His obituary giving an account of his career and achievements has appeared in all the major British newspapers, giving some indication of the standing he had in society in general but the thing that comes through all the tributes to him is his deep humanity and total lack of any sense that he felt himself above other mortals intellectually. Chemistry World for June has a memorial issue commemorating the past President of the Royal Society of Chemistry. Malcolm Heggie as our Chair and a personal friend, gave a tribute on the BBC Radio 4 programme “Last Word”.

It is too early to give any news about commemorative events, although there are indications that carbon groups internationally feel that his name should be perpetuated by a named lecture and medal but this is as yet in the preliminary stages of discussion. The BCG will however take a leading role in any such events.

It has been a busy year for the Group. After the Spring meeting at BAT, and our annual Nanotec meeting, this year at Oxford, we had the INGSM 16 meeting at Nottingham, followed by the “Carbon at Christmas” meeting at the Society of Chemical Industry’s HQ at Belgrave Square, London. A notable feature was the award of the Carbon in Industry prize to Prof Steve Tennison after which he gave the lecture associated with it. He was well supported by two other invited talks on diamond and on a novel use of graphene in gas separation. Accounts of the lectures are given in the newsletter.

Participation was invited in this meeting by means of a photographic competition on the theme of carbon at Christmas. A number of photos (and one cartoon) were submitted and appear here. The first prize of £100 was awarded to was Ceren Zor of the 'Nanomaterials by design'. The runner up was Lan Nguyen.

We have also just had our AGM during the meeting at Southampton on nuclear graphite. Your committee was re-elected en bloc with the addition of Izabela Jurewicz and a welcome back for Sergei Mikhalovsky. Malcolm Heggie did say however in his Chairman’s report, that we do need fresh blood on the committee. I hope that any member reading this who feels that he or she might be able to take part in the committee’s activities will approach a committee member and find out what’s involved. It’s not onerous work but it is vital to continuing the work of the BCG.

Or next meeting will be NanoteC 2016, held this year in Dublin. We are also provisionally taking part in the RSC Faraday meeting in 2017, a new venture initiated by the Divisional President, Prof. Eleanor Campbell. I am glad to announce that Prof. Campbell will give the next Ubbelohde lecture, the date and place yet to be decided.

The rest of the UK has decided that we are leaving the EU. The consequences for scientists here and indeed the rest of Europe will be much more profound and direct than for the majority of the population. It scarcely needs me to reassure you that the policy of the British Carbon Group will remain international in outlook and we will endeavour to maintain the links we have with allied organisations and workers in the field of carbon overseas.

Norman Parkyns

Tributes to Harry Kroto

Sir Harold Kroto, FRS, Nobel Laureate, never wanted to be addressed except as “Harry”. He has had more formal tributes paid to him in the national and scientific press but I am pleased to be able to give here rather more personal memories of former colleagues who worked with him at Sussex University. My own contact with him occurred when I was working for British Gas R&D and one of my colleagues who had graduated from that university said that he had been talking to one of the senior researchers there who had some novel ideas about carbon that he would like to talk to us about. That sounded promising so I rounded up some of my colleagues to listen. Harry turned up in an open-necked shirt, not so usual in the 80s as it is today, with his papers carried in a rucksack. He then of course revealed the early work he had been doing in the USA with Profs. Curl and Smalley on C60. I am glad to say that it sounded totally convincing to me: it felt so absolutely right. My colleagues were similarly impressed and I’m glad to say that we manage to find some money to support further work both for equipment, a high-power transformer (!), and for a research student Jonathan Hare, who gives his tribute to Harry below. Before that we have a more formal tribute paid by Mauricio and Humberto Terrones.

Norman Parkyns

Harold Walter Kroto: A carbon scientist, humanist, spectroscopist, graphic designer, tennis player and friend (1939-2016)

Harold W. Kroto, who always wanted to be called “Harry”, was an outstanding and charismatic scientist, excellent communicator and humanist. Fascinated by science and graphic design, he believed that the scientific method and in multidisciplinary research were key for achieving transformative breakthroughs. He was always an active supporter of the Carbon Journal and produced an impact in the young and more senior generations, not only by his mentoring within a freedom atmosphere, but by his dedication to the dissemination of good science to children, youngsters and the general public.

Harry was born during the first month of the Second World War, on October 7th, 1939 in a very small town in Cambridgeshire (United Kingdom). Son of German immigrants, he and his mother were separated from his father during the war because he was interned on the Isle of Man. A year later, Harry and his mother were moved from London to Bolton, where he spent all his childhood. After the war, Harry’s father joined him and his mother, and he first became a qualified toolmaker in an engineering company.

During his childhood, Harry did not have much school holidays since he worked with his father in a family-own balloon factory. However, at that early stage he learned important concepts of chemistry, physics and math other kids could not. For example, he mixed latex dyes, repaired machinery and replaced workers. His parents also wanted the best education for Harry and he was enrolled into the Bolton School which was full of excellent teachers. At this point, Harry also had a truly strong attraction to the “Meccano set”, which he played over and over. He was a “Meccano boy” and in his lectures, always mentioned the fascination he had for it. In addition, Harry was an excellent tennis player and enjoyed gymnastics.

His interest in chemistry became stronger as time passed by. He was indeed attracted to organic chemistry and encouraged by his chemistry teacher, he decided to study chemistry at Sheffield University. In parallel to chemistry, he had an immense fascination for art and design to the point that at home, he only had art and design books. During his graduate education, Harry won the Sunday Times book jacket design competition. He made several designs that went to print and Harry was extremely proud of his artistic portfolio. His artistic attributes were also present in his daily scientific activities, as he played particular attention to the layout of slides, plots, diagrams graphics, and animations.

Although Harry was attracted to organic chemistry at the university, he had a big transition to physics and physical chemistry, when he got introduced to quantum mechanics and spectroscopy by Richard Dixon. Subsequently, during his PhD he researched the spectroscopy of free radicals produced by flash photolysis and graduated in 1964. In 1963, Harry married Margaret H. Hunter and a year later they decided to have an experience abroad, and Harry got a postdoc offer at the National Research Council in Ottawa (Canada). He worked with spectroscopists (mainly physicists), and then got excited about microwave spectroscopy. After learning in-depth quantum mechanics, Harry realized that he could complement his fellow physicists with his strong chemistry background, and he then found his own scientific niche.

After two years in Canada, he moved to Bell Labs and carried out experimental work in Raman spectroscopy and theoretical calculations on electronic transitions of small molecules and radicals. In 1967, he was offered a postdoc position at Sussex University (UK) and a year later, when Harry started to look into the possibility of even contacting Richard Buckminster Fuller for a research position in design, he got a lectureship offer to stay at Sussex where he stayed until 2004. At Sussex he continued working on microwave-, Raman- and photoelectron-spectroscopy, and programed his own codes in order to carry out theoretical calculations. He soon became an experiment/theory chemical spectroscopist. In 1974, after acquiring his own microwave spectrometer, the first molecule Harry started to study with the new spectrometer was HC_5N (a family of molecules called polyynes), and this became the genesis which triggered the discovery of C_{60} with Curl, Smalley, Heath and O'Brien, with the subsequent emergence of carbon nanoscience.

In the mid-70s, Harry got more and more interested in understanding the chemical composition of interstellar medium using radio telescopes that were capable of acquiring microwave rotational emission spectra of distant molecules from other galaxies. With his knowledge of chemistry, spectroscopy and radio astronomy, he then became the pioneer in the field of *astrophysical chemistry* or *interstellar astrochemistry*. Soon after he recorded the microwave rotational spectrum of HC_5N, Harry contacted Takeshi Oka (whom he met during his postdoc at NRC-Canada), and asked him if was interested in looking for this particular chain molecule using a radio telescope. To their surprise, they found this molecule in relative abundance towards in a giant molecular cloud in the center of our galaxy.

At this point, Harry started to work closely with David Walton (also at Sussex) who was synthesizing longer polyynes (HC_nN) where n=7,9… Subsequently, these linear molecules were also detected in the outer space from cool red giant carbon stars. In the early 80's,

Harry started to interact with Bob Curl and after reciprocal visits to Sussex and Rice University (Houston), Harry met Rick Smalley whom he had a beautiful piece of cluster science equipment, consisting of laser vaporizing metal targets, expanding these species supersonically and detecting them in a time of flight mass spectrometer. Harry then suggested to try graphite as a target in Rick's molecular beam apparatus, and in August 1985, Bob Curl called Harry and told him they were ready to try graphite in Rick's laboratory. Harry believed that the extreme conditions of Rick's experiments were similar to those occurring in red giants stars, and speculated that even longer polyyne chains could be produced and identified. In September 1st, 1985 the Rice-Sussex team found these linear chains and Harry confirmed his theory. However, on Wednesday September 4th, during data acquisition the team also noted the presence of a huge signal with a mass of 60 carbon atoms, which lead to the discovery of the most beautiful icosahedral molecule, C_{60}: Buckminsterfullerene. This name was given in honor of the famous architect Richard Buckminster Fuller, whom Harry wanted to work with after his postdocs in the mid-60s.

At that point, Harry became a carbon scientist and continued searching for methods to produce bulk quantities of C_{60}, because only minute amounts were produced in the molecular beam experiments. As a carbon scientist, Harry thought that carbon soot synthesis could also lead to the production of C_{60}. In the 80's Sumio Iijima also reported the cross section of small concentric soot particles produced by evaporating carbon electrodes using transmission electron microscopy; Harry thought that C_{60} could have been the inner most shell of these soot particles. Harry introduced the concept giant icosahedral fullerenes by having only 12 pentagons and any number of hexagons, and explained the sphericity of soot particles. It was this soot who drove Harry to perform arc evaporation experiments with Jonathan Hare, a Sussex PhD student. After reading a publication in the late 80's from Krätschmer, Fostiropoulus and Huffman, reporting 4 peaks in the Infrared spectrum of soot possibly coming from C_{60}, Harry asked Jonathan Hare and Amit Sarkar (an undergraduate project student) to reproduce the results and asked them to dissolve the soot in toluene for mass spectrometry; the solution was reddish and was laying on Harry's desk. However, only a few days later, Harry got devastating news. He received a paper to review in *Nature* from Krätschmer and Huffman, reporting the bulk synthesis of C_{60} using the arc discharge method and also reported the reddish solution. He accepted the manuscript but felt disappointed he missed the C_{60} synthesis. Soon after, he decided to use his chemistry background and teamed with Roger Taylor (and others at Sussex) to separate C_{60} using a chromatography column. The Sussex team was then the first to report the NMR spectrum and confirmed the symmetry of C_{60}; a truncated carbon icosahedral cage, containing 20 hexagons and 12 pentagons, and all carbons sp^2 hybridized. At the same time, C_{70} and other larger fullerenes were extracted as well as the NMR signals. At this point, another breakthrough in carbon science was achieved, the synthesis and extraction of fullerenes. From there, Harry and colleagues at Sussex carried out fundamental work on physics and chemistry of C_{60}, C_{70} and higher fullerenes.

These events constituted the emergence of carbon nanoscience. Only a few months after the synthesis and isolation of the third allotrope of carbon (C_{60}), other carbon researchers in the US such as Mildred S. Dresselhaus, Richard Smalley and others brought up the novel

idea of a single-walled carbon nanotube (an elongated fullerene or a rolled graphene cylinder), having one-dimensional density of states and with well-defined van Hove singularities. However, many experimentalists wondered if such elongated molecules could be synthesized. Soon after, Iijima reported the crystalline structure of arc discharged-synthesized (using the Krätschmer-Huffman fullerene reactor), nested carbon nanotubes or elongated giant fullerenes. Nonetheless other key reports on the pyrolytic synthesis of single- and multi-walled carbon nanotubes were published in the mid 70's by Morinobu Endo and Agnes Oberlin. Since then, the synthesis and applications of carbon nanostructures led to an impressive research activity worldwide.

In 1996, Harry together with Bob Curl and Richard Smalley were awarded the Chemistry Nobel prize for discovery of Fullerenes. In the mid-90's, Harry and David Walton also created the Fullerene science center at Sussex University, and initiated an intense research program on fullerene chemistry, solid state physics/chemistry and nanotube science. Several accomplishments with Paul Birkett, Malcolm Heggie, Roger Taylor, Kosmas Prassides, Tony Stace, and others were published in the best journals. Harry was also convinced that having a truly multidisciplinary effort of graduate students and postdocs was key in the fast development of carbon nanoscience. People like Steve Acqua, Perdita Barran, Simon Balm, Ana Benito, Jonathan Crane, Adam Darwish, Bernd Egen, Chris Ewels, Steve Firth, Nicole Grobert, Wen Kuang Hsu, Ken McKay, Thomas Mueller, Douglas Reid, Mauricio Terrones, Martin van Winjkoop, Raymond Whitby, Yanqiu Zhu, and international collaborators including Morinobu Endo, Eleanor Campbell, Tony Cheetham, Sydney Lych, Humberto Terrones, Fred Wudl, and others worked towards the end of the 90's and reported seminal scientific achievements.

In the mid 90's and in parallel with the research activities, Harry and Margaret Kroto established The Vega Science Trust in which Gillian Watson, Jonathan Hare and Chris Ewels took an important role. As primary objective, this charity focused on the promotion of Science to the young generations, but it had to be disseminated by scientists themselves. He first established a program called "Master Classes" in which he invited prominent scientists to discuss and debate important topics such as the chemical bond with John Murrell, the life of Bernal (Chris Freeman), bird evolution (John Maynard Smith), etc. The program evolved rapidly and extensive archive of videos, interviews, are available at http://www.vega.org.uk/. Simultaneously, Harry established kid's fullerene workshops where he engaged children telling the story of C_{60}, nanoscience and nanotechnology. These workshops were organized all over the world and children everywhere had the chance to build the most charismatic molecule, C_{60}.

In 2004, Harry moved to Florida State University (FSU) and continued working on carbon nanoscience until the end of his life. At FSU, he worked with Steve Acqua and Paul Dunk. In particular, Harry came back to the carbon cage genesis and together with Paul Dunk using a carbon molecular beams using C_{60} targets, confirmed the fullerene growth by C_2 addition. From the educational standpoint, Harry created the Global Educational Outreach for Science, Engineering and Technology (GEOSET), and continued outreaching to the Young

generations. At present Steve is leading this magnificent effort supported by Florida State University.

Very recently, in July 16th, 2015, during a workshop celebrating the 30th anniversary of the C_{60} discovery (co-organized by the Royal Society of Chemistry and The Royal Society), John Maier and his group presented to Harry that the diffuse interstellar bands observed long time ago and that were not identified, were in fact coming from C_{60}^{+}. These results appeared in *Nature* that same day. The result was predicted by Harry in 1987! Harry used to say "C_{60}: The celestial sphere that fell into Earth". His predictions were correct and it is indeed coming from outer space, but thanks to Harry it stopped by on Earth, and triggered the development of carbon nanoscience.

Sir Harry Kroto at the Royal Academy Summer Exhibition in London (July 2015). Standing from left to right: Nazario Martin, Humberto Terrones, Fred Wudl and Mauricio Terrones.

Harry was a frequent traveller, never stopped carrying out research and continued stimulating young generations with the impact of science in society. In the summer of 2014, Harry was diagnosed with amyotrophic lateral sclerosis (ALS), but this did not stop him. In the April 2015, Harry and Margaret decided to move back to Lewes in the UK. However, he continued with his travels, research and outreach activities, until March 2016. The 30th of April, 2016 Harry passed away in company of Margaret, his sons (Stephen and David), and close friends.

Harry, you changed the life of many people and not only contributed to science and the training of new researchers, but also influenced many children who are now carrying out research activities and some in carbon science. For those who you reached, you will always be present. Thanks Harry for your all wisdom: Your legacy will prevail. Finally, a quote from Harry Kroto:

"Some people think that Science is just all this technology around, but NO it is something much deeper than that. Science, Scientific thinking, Scientific method is for me the only

philosophical construct that the human race has developed to determine what is reliably true"

Mauricio Terrones and Humberto Terrones

Working with Harry Kroto

I studied for my PhD with Harry Kroto from 1989-1993, working on the extraction of C_{60} and then stayed on in the group for about 10 years before becoming a science communicator. It was a fabulous time and a real privilege to be able to spend so much time working closely with such a remarkable inspiring, creative and kind man.

Harry had a great ability to get to the heart of a problem; it was very interesting and inspirational to watch this going on in a meeting or in a conversation. It sometimes made me almost laugh out loud when I had been struggling to understand something for ages and then to have it explained so quickly and simply! Part of this I think was his ability to concentrate deeply, but perhaps more importantly his ability to see things clearly – that's a great skill for a scientist (and of course an artist). I remember on many occasions how his intense focus seemed to make my own limited concentration feel sharper.

I loved the way he was so free at taking up new ideas and new directions for the sake of curiosity and possibilities - his favourite catch word was "interesting". He very much encouraged us to look for, and explore new areas of research for ourselves - this attitude it seems is not so common! He seemed to have managed to keep some inner curiosity, creativity and drive which others have sometimes lost. In addition to this when negative things happened (an experiment didn't work or something failed) they did not seem to put him off at all but contributed to his line of thinking and research and he would often be able to put it to some good use.

He made me realise it's worth pursuing a new idea / area not only because it may reveal something new but also (and perhaps more importantly because ideas never really work out the way you dreamed they would) that this learning is a process worth doing in its own right.

Harry had a vital enthusiasm and interest in the world - chatting to him was inspirational, clarifying and often a lot of fun. He was often very generous sharing his ideas and work. His energy and success also helped a lot of people all around the world, to follow their own aspirations and inspirations. He thought creative freedom was important for each of us and for the future of the world.

Some stories

A special treat

Harry and I presented 100's of C_{60} workshops both together and separately. On one occasion we were giving a workshop to about 100 eight to nine year olds and the Head Teacher introduced us saying "you are getting a very special treat today". Of course what teachers mean and what children hear are often different things. The teacher meant the 'treat' was to meet Sir Harry Kroto. As was usual in our workshops half the event was a set of fun science exercises and then the second half would be getting the kids to make up their own C_{60} model. At this halfway stage one of the children came up to Harry and I. He had obviously been thinking a lot about what the 'special treat' could

possibly be and took us both aside and said hopefully, "is it pizza?" Luckily children are very resilient and he seemed happy enough to make his Buckyball!

The BA Festival and Patrick Reams

In 1994 Harry and a BBC producer Patrick Reams, set up the Vega Science Trust. Vega was managed by Gill Watson for many years. We were at a BA Festival of science meeting one year and Harry and Patrick were giving a talk about the Trust. We had all met up for breakfast and were now about to pop over to the venue in Harry's car. I had got in the front seat, Harry in the driving seat. Patrick had opened the back door and thrown his case onto the back seat but could not get in because of piles of gear. So he slammed the door aiming to go around the back of the car and get in via the other door. Harry was keen to get to the venue in plenty of time to make sure the video projector worked ok, so when Patrick had slammed the door we speed off at high speed. We were both talking to Patrick from the front of the car but he was very quiet. Eventually we came to a set of red traffic lights so we had to stop and on turning around to talk to Patrick he wasn't there !! "Patrick, where's Patrick!?" Harry exclaimed! Looking through the car window I could see Patrick 'pegging it' along the road trying to get to us before the lights changed. The thing is that when he got to us and finally got his breath back, he wasn't angry at all. Quite the opposite, we all laughed - you just could not really get angry with an impatient but enthusiastic Harry - it's just the way he was.

My first lesson with Harry - seeing things clearly

Before I worked on the extraction of C_{60} I spent a few months analysing data sent back from the Ghotto space probe; results that would be my first published scientific paper! In 1980's Nasa sent a space probe to analyse the composition of comet Halley's tail (the material ejected into space from the comet when it gets heated up by being close to the Sun). In my first year of my PhD I would use Friday mornings to go over to the Sussex University library to read the latest science journals such as Nature and Science.

The first papers had come out on the Ghoto mission data and so I photocopied them to show Harry. I knocked on his office door, he said "Come in" and as I laid the paper on his table I said "Wow! Harry, have you seen this ... its .." , I was going to say "great" but he but-in and finished off my sentence by saying "... isn't it crap!". I could not believe my ears. Nasa has predicted what they might find (a type of polymer), had built the probe, sent it million of miles through space, it had successfully met Comet Halley and also successfully sent back data AND the data fitted the prediction - what was there not to like!? It was one of those 'blow your brains moments'. I thought 'have I just signed up for 4 years with a mad person!' Harry said the polymer might be there but he told me to drop everything I was doing and to focus on this project. "Go and get a random mixture of molecules, find out how they will fragment and plot the data and come back to me with the results". He told me to take the Urey-Miller primitive atmosphere experiment results as the 'random' mixture and to get Simon Balm (a final year PhD student) to check the results and write a program to integrate to the same resolution as the Nasa data. We did just that and found the 'random' organic data fitted perfectly! Of course it did what else would you expect - once you think about it properly! Harrys genius of course was not, in this case, his encyclopaedic knowledge of chemistry, astronomy or physics, it was his ability to see the 'wider picture', to clearly see what was most likely. He was not put-off or swayed by others' theories or eminence (Nasa). He was simply able to ask 'what is the most likely explanation of this data?' That was a massive lesson for me - a real step change and inspiration for me. I never really quite got over it; it changed my whole idea of what science could

be. He showed how a few minutes of clear thinking could provide a more realistic explanation of this problem than years of other people's work and millions of dollars! In the end, seeing things clearly is what it's all about - but it's often surprisingly hard to do.

Photo taken at the 30 years of C60: Past, Present and Future Conference July 2015, RSC

London. From left to right: HumbertoTerrones, Nicole Grobert, Harry Kroto, Daniel Ugarte, Jonathan Hare & Mauricio Terrones.

Jonathan Hare, May 2016

Entries for the "Carbon at Christmas" photographic competition, December 2015

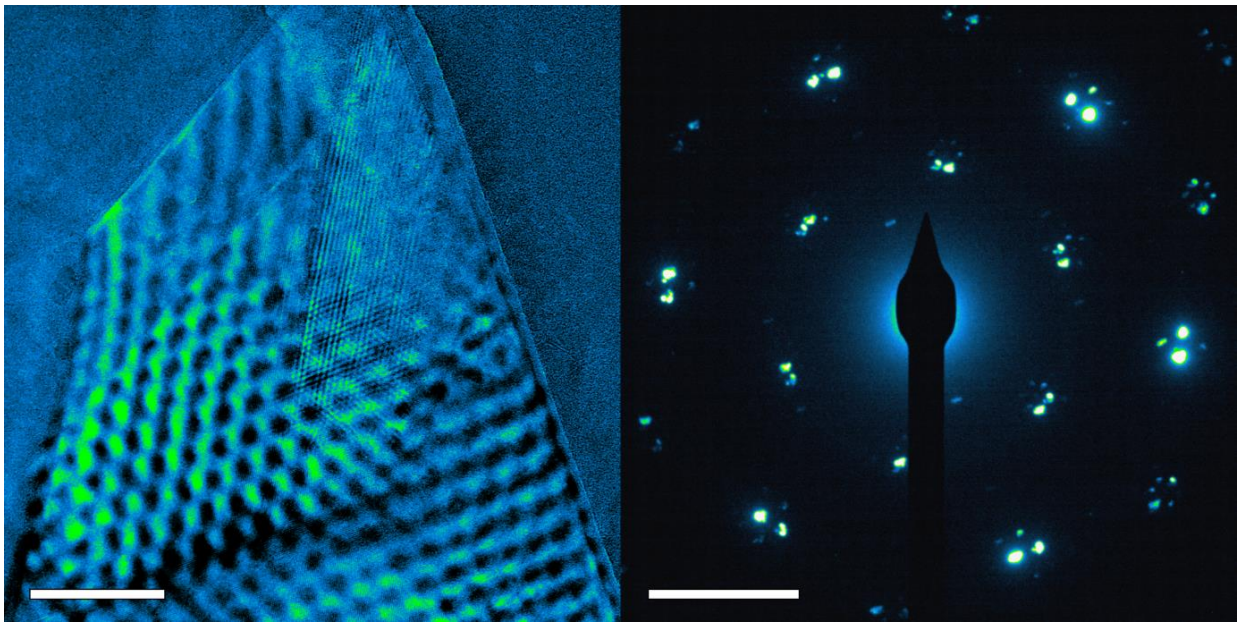
Activated Carbon: The Black beauty **Thanuja Galhena, Cambridge**

This is a false coloured SEM image of activated carbon particles

Sang Froid Lan Nguyen, Manchester

The LHS of the image is a TEM image of incommensurate graphite stacks creating a Moire pattern. The RHS is the corresponding “snowflake” diffraction pattern that reveals the different orientations and periodicities of the graphene sheets.

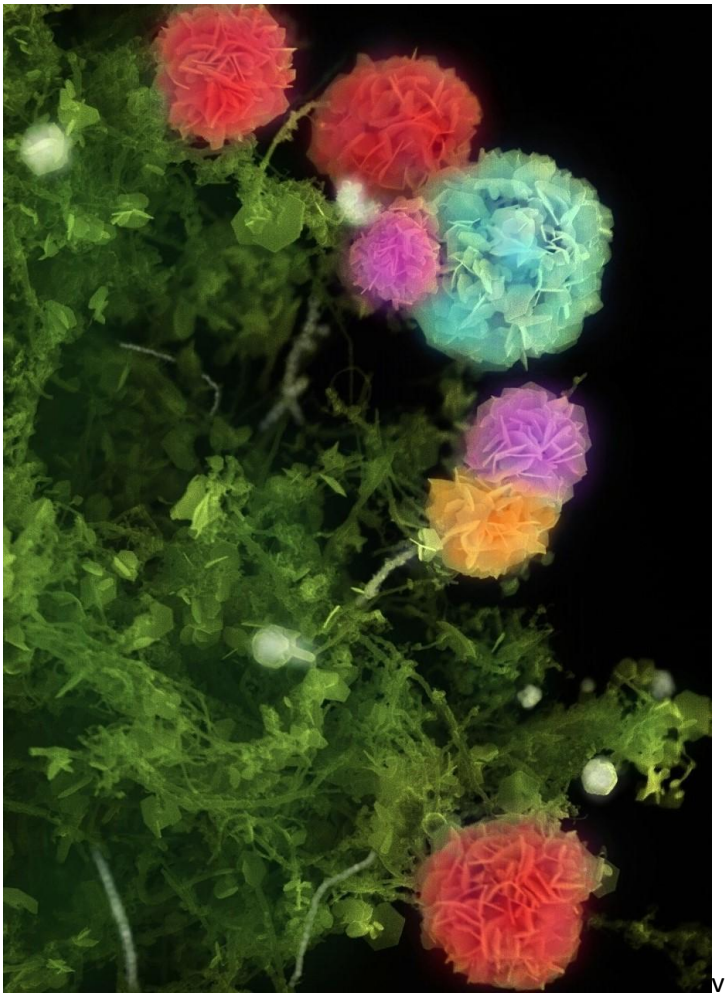
LH scale bar is 100 nm and the RH is 5 nm^{-1}. The image has been false coloured



Winning entry Decorating the Christmas Tree: SEM of carbon-based hierarchical nano materials.

Ceren Zor, Oxford

The artificial colour image was created within the Nanomaterials by Design Group led by Prof. Nicole Grobert.



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Graphene Oxide: New life to an old Material Thanuja Galhena

Collection of false -coloured SEM images (left, top right and bottom right) of a free-standing GO paper with a top view of a solution (mid right)

Forthcoming meetings

NanoteC16

NanoteC is one of the BCG's premier meetings and this year it is to be held at Trinity College, Dublin. Details are given below in the meeting notice that shows where to get more information.

INGSM17

This year's meeting of the International Nuclear Graphite Specialists Meeting will be held in Vienna, at the invitation of the International Atomic Energy Agency (IAEA). It will continue its association with the BCG and EDF and is being organised as usual by Tony Wickham. Full details can be obtained by him at confer@globalnet.co.uk .

Reports on past meetings

I have first to indulge in a bit of *mea culpa*. In my report of his Ubbelohde lecture, I misreported Peter Thrower in one or two places, for which I hang my head in shame. He has sent in a short and very polite correction to put the record straight, so here it is. *ndp*

Dear Norman:

On Christmas Eve I received the BCG Newsletter and have now managed to find time to read it. There are a couple of errors in your report of my talk and I am not sure whether at least one of them should be noted. Perhaps it depends on whether Sir John is likely to read it?

It was my boss at Harwell (John Simmons) who had predicted the release of stored energy and was consequently appointed to head the new Carbon and Graphite Group. John Thomas was never a colleague at Harwell, and at that time was at the University of Aberystwyth. My mention of John Thomas was in relation to a photo I showed of Phil Walker, Harry Marsh and him standing by a road

sign for “Graphite” - a small hamlet in New York State, where they were searching for the famous Ticonderoga graphite deposits.

Also, the different heat treatments at Harwell and Cambridge resulted in different nucleation mechanisms for radiation damage in the graphite crystals. Sintering was not involved.

Report on the NanoteC15 Conference

Attendance of this year’s NanoteC15 conference at Corpus Christi College, Oxford proved very motivational and informative about new and old areas of carbon nanomaterial research. The four day conference covered many different areas of carbon nanomaterial production, application and characterisation. I will summarise the presentations that have mainly influenced myself in the energy device sector and plasma treatment of materials.

Claudia Struzzi, University of Mons, gave a presentation and two posters associated with the plasma fluorination of supported and suspended graphene and vertically aligned carbon nanotubes. The plasma functionalisation method was extensively analysed with in-situ scanning photoemission microscopy that can capture SEM images, XPS and micro-Raman measurements of the fluorination process.

The Dalton group at the University of Surrey gave many varied presentations through-out the conference. Alice King discussed dry spun carbon nanotube fibres and the integration of silver nanowires for electrical conductivity improvements. Matthew Large instead described his work with graphene films and silver nanowires to replace indium tin oxide in electronic devices.

The application of these materials in energy devices was a popular topic. Paolo Bondavalli from Thales, divulged impressive specific capacitance results of graphene oxide and oxidised carbon nanotubes sprayed into electrodes with a novel deposition process. Sun-Hwa Yeon presented new technology from Korea Institute of Energy Research (KEIR) to produce reduced graphene oxide for supercapacitors.

The underlying key with many of the applications discussed was dispersion of the nanomaterials in solutions and liquids. Typically this is aided with chemical functionalisation of the surface – which was discussed by Rosa Menendez from INCAR, however this can be known to damage the crystallinity and structure of the nanomaterials. Haydale’s plasma functionalisation technology could have the solution, by functionalising the surface using low pressure, low temperature plasma technology without causing degradation of the materials. The process is large scale from 10 to 1000 g, which could have made academics anxious. However, when the production of single-layer graphene sheets is developed into larger quantities, then this process could be key to dispersing these materials in a consistent and non-degrading way. Chris Stirling presented Haydale’s technology at the conference and its application in supercapacitors.

Wolfgang Maser from the Instituto de Carboquimica presented his research on many biological applications of graphene oxide. A graphene-based potentiometric biosensor can be used to detect bacteria and an amperometric biosensor with gold nanoparticles anchored on reduced graphene oxide can be used for sensing the l-lactate tumour biomarker.

The best presentation award was given to Vitaliy Babenko, from the University of Oxford. All of his peers gave very interesting talks and Vitaliy’s was especially intriguing on the growth of large area, high quality graphene crystals using substrate engineering and eutectic layer formations. The poster

prize, sponsored by Haydale, was awarded to Piers Turner from the University of Surrey and NPL. His poster was on acoustic cavitation, a more in-depth study of ultrasonication, to produce efficient dispersion of graphene and other 2D materials.

Overall, the conference was insightful and well organised. I presented a poster at the conference, a career-first, and got some very insightful feedback from academic and industry specialists. I look forward to attending a future NanoteC conference with plenty more results and conclusions to discuss, hopefully!

Emily Smith

Conference Report

Graphene Week 2016 in Warsaw, Poland

The 11th edition of the international conference, Graphene Week 2016 was held from 13th to 17th June in the capital of Poland on the main campus of the University of Warsaw focusing on the science and applications of graphene and related two-dimensional materials by bringing together international key experts and professionals from all around the world. As a young researcher who is working on carbon based materials for energy storage applications, I got the opportunity to attend this *too–good-to-miss* event, thanks to the generous financial support from British Carbon Group.

Over 700 conference delegates including, key graphene experts, up-and-coming researchers, entrepreneurs and journalists paid close attention to a number of fascinating talks and posters ranging from the fundamental science of graphene and other 2D structures, through to practical applications of these materials such as in energy conversion and storage, graphene pressure and humidity sensors, spintronics and biomedical applications. It was interesting to learn how the influences from the natural world can be used to make better graphene devices and how those new and surprising phenomena emerge when you pluck out a carbon atom from the graphene structure and make graphene imperfect.

At the conference, I presented my work on understanding the capacitance variation in sub-nanometre pores by in-situ tuning of interlayer constrictions in graphene based electrodes. Here, I introduce a model system based on graphene oxide to understand the contribution of sub-nanometre pores in carbon electrodes to the charge storage mechanism in supercapacitors. This employs interlayer constrictions as a model for pore sizes that can be both controllably tuned and studied in-situ during supercapacitor device use. This novel approach circumvents the debated use of complex pore size distribution evaluations (DOI: 10.1021/acsnano.5b05819). Also, I got the opportunity to discuss my work on activated carbon based supercapacitors with the expertise in the field.

This year, the addition of the Graphene Innovation Forum was a unique opportunity for the young researchers who look forward to commercializing their research. The forum has been introduced to the conference to bring specific focus on innovation aspects of graphene and standardisation of graphene. Also, it hosted a very successful “Women in Graphene” event which gave women, and male allies, the opportunity to speak openly about the barriers to entry of women in science and what might be undertaken to break them down, and improve current gender imbalance. Running throughout the Graphene Week was the conference exhibition, where exhibitors from industry and academia showcased what they have to offer. It was a fascinating area to visit, where there were many different prototypes to view and

interact with. The welcome reception and the conference dinner, which were held in the stunning surroundings of Warsaw Grand Theatre and the Royal Castle respectively, provided incredible atmosphere and a great opportunity for many un-official discussions about graphene, general networking and future planning.

Participation in this conference gave me the valuable opportunity to meet potential collaborators both from industry and academia, learn about new career opportunities and training programmes for scientists, find possibilities for commercialising my research and meet science journalists to learn more about publishing my research. Therefore, I cannot stress enough how grateful I am to the British Carbon Group for the financial support that has been offered to me to experience this fascinating event. Thank you BCG!

D T L Galhena MIET MRSC
Department of Engineering, Electrical Engineering Division, University of Cambridge

"Carbon at Christmas" SCI, London 17th December 2015

The BCG has had a tradition of having a meeting on several aspects of carbon at Christmas. This year it was held at the excellent lecture theatre at the headquarters of the Society of Chemical Industry at Belgrave Square. Three extremely good presentations were given to the audience, which although fewer in numbers than one would have wished, thoroughly appreciated the very high level of the work that they heard.

The meeting was also the occasion to present the SCI/BGC "Carbon in Industry" award to Prof. Steve Tennison and to hear the lecture associated with it. Steve said that he felt very honoured by this award and took as his starting point his Ubbelohde lecture to the Group in 2008. Since then, the carbon industry was even more valuable than it had been then. New problems and opportunities had arisen that needed new carbons to deal with them. He mentioned supercapacitors as an example. The approximately 10% annual growth was largely driven by environmental applications, an example being the need to remove traces of mercury from stack gases in the USA. His own firm, MAST Carbon Ltd, however had its interests in the speciality, rather than the bulk, carbon market. In the latter, where active carbons are made by pyrolysis and subsequent activation in rotary furnaces, the adsorption properties were very variable as a consequence of this processing. This was of little importance in the large-scale applications like water purification but made them very difficult to use for specialist purposes. It had been established for some years that polymer-derived carbons could give much less variability as well higher purity and this is what his firm's products concentrated on. Carbons derived from phenolic resins besides being good adsorbents were especially mechanically strong. Their nanoporosity derived from space between micro-domains, quite unlike the slit-shaped pores in conventional carbons. At very high carbon burn-off, there was a distinctive bimodal porosity distribution. If one stopped at lower burn-off, there remained a single mode distribution. However, a well-developed meso-pore structure acting as feeder pores allowed molecules of very high molecular weight to enter. Such carbons also allowed much more control over the surface properties, for example, by introducing oxygen functionalities to the normally neutral surface by activating in nitric acid.

These carbons found application in personnel protection against toxic gases. A good example was in the fabrication of hoods for first-aiders who were the first line of defence in dealing with casualties from an attack or where there was an industrial incident. These hoods needed to be put over the head quickly, at the same time allowing the wearers to see and allowing them to breathe easily. This

last point was easily dealt with by inserting canisters of the carbon into the airways as not only did they adsorb undesirable constituents but because of their unique monolithic construction had a very low pressure drop while continuing to have a very high rate of removal of toxic gases, fully comparable with dispersed carbon granules. Prof. Tennison showed examples of both the carbon monoliths used and the type of plastic hood in which they are fitted.

These carbons also have application in the water purification in removing the last traces of high molecular weight toxic materials. In the UK, removal of metaldehyde is necessary and not removed by conventional active carbons but easily taken out by the phenolic-derived carbons. They can be used also for clean-up of effluent from industrial and chemical plants.

In biomedical applications, the molecular weight of toxic materials can reach 1000kDa and these clearly need large pores in the carbon to allow them to get to the nanopores that adsorb them. He mentioned a couple of major potential applications, those of sepsis after heart operations and liver failure, which was potentially treatable by oral intake. Trials with EU funding on small animals were in progress on these topics.

He finished by very brief reference to two other areas where these carbons held promise, that of supercapacitors and making safer Li-ion batteries.

His talk was enthusiastically received and at the end of it, he was presented by Prof. Malcolm Heggie with the Carbon in Industry prize award.

Dr Tim Mollart of Element 6 then talked about how synthetic diamond is used in industry. Synthetic diamond is now used on a scale 150 times that of the natural stone. It's a $2bn market, mainly in cutting and grinding applications, in the oil and gas industry and for precision machining and grinding. The synthetic material can be more precisely tailored for such applications compared to natural diamond. The High Pressure High Temperature (HPHT) was developed first but Chemical Vapour Deposition (CVD) came later in the 1980s and has increased in importance ever since especially in the new areas of industrial lasers, thermal management devices and industrial electrotechnology. Element 6 make 300 te/year by the HPHT process alone: the CVD process uses methane as carrier gas and source of carbon and is decomposed in a microwave plasma. CVD is preferred where the end product is doped as it is much easier to control. Discs up to 6" diameter can be produced in this way.

A key property of diamond is its very high thermal conductivity, which leads to it being used for heat management in electronic devices. This is a market that was formerly very important but is coming back into vogue with the development of high power GaN devices. Electronic properties of diamond are easily altered by controlled doping, changing it from a virtual insulator to a semi-conductor of very low band gap. Boron doping turns diamond blue and only 1 atom in 2000 will change it to a metallic conductor. One problem with using B is that it encourages the formation of sp^2 C-C bonds that have undesirable catalytic properties in electrochemical applications. Clean-up of organic material in aqueous solution can be achieved by producing OH radicals: diamond electrodes allow the production of this species without concomitant water splitting. An interesting application is cleaning –up leachate from landfill by this means.

After Dr Mollart's talk, the title of Dr Lozada-Hidalgo's presentation "Proton transport through 2D crystals" sounded to me rather dry. It is good therefore to be able to report that it was anything but and at least as interesting as the two preceding and formed a very strong close to the meeting. His work at the Graphene Centre at Manchester was based on seeing what happens when single layers of graphene and other 2D materials are trapped between Nafion surfaces. Graphene besides being

the strongest material known is also impermeable to gases. Protons are quite large, at least when encountered as H_3O^+ and in theory should not be able to pass through the graphene layer. However, he had made up an electrochemical cell where graphene layer or layers as well those of BN and MoS_2 were sandwiched between two Nafion blocks. If hydrogen gas was allowed to contact one of the Nafion blocks and an electric potential applied, protons migrate through the Nafion and also the graphene layer. The rate of diffusion of protons was measured by mass spectroscopy of the transported hydrogen and the mass of gas diffused was exactly proportional to the current passed. Hexagonal BN layer transported protons even more readily but MoS_2 did not. Moreover, when a bilayer of graphene was used, that also did not allow protons to be transported. It may be that the stacking of the carbon atoms is different in the second layer.

The conductivity of graphene is activated with an activation energy of 0.8eV, that of BN being 0.6eV. At 250^0C, the conductivity of the graphene or BN becomes many times that of the Nafion. Decorating with Pt decreases the activation energy dramatically.

That this was not just an academic exercise was shown by what happens when the experiments were repeated using deuterium. In this case, the rate of diffusion at room temperature is about 10 times less than for protium. This leads to the possibility of industrial applications in separating these two isotopes and possibly, other gases. Their thinking at present is that the difference in diffusion rates is due to differences in zero point energy for deuterium and protium.

At the end of the meeting, Malcolm Heggie announced the winner of the £100 prize for the best photograph invoking Carbon at Christmas. The committee had unanimously agreed that the contribution from Ceren Zor, Department of Materials , University of Oxford was the winner for the photo entitled ”Decorating the Christmas Tree; SEM of carbon-based hierarchical nano materials”. He was not able to be present at the meeting but will receive his prize in due course.

We are grateful to the SCI not only for providing the use of their lecture theatre but also providing elegant programmes for the meeting where the winning photo and all the entries were reproduced in full colour.

Norman Parkyns

News and announcements

The British Carbon Group

The SCI 'Carbon in Industry' Award and Lecture 2016

This prestigious award was established by the Society of Chemical Industry and the Award will be given for the sixth time in 2016. The award seeks to recognize the contribution made by leading industrial scientists and engineers to carbon science and technology such as any significant contribution to developmental work, pre-commercialization, and / or promoting interaction with other sectors of society, e.g. public understanding of science.

Nominations are now requested without the knowledge of the candidate and with a supporting 250 - 500 word citation. The BCG Awards Committee will then determine the awardee on the basis of independent scoring against the criteria of track record, citation submitted and industrial impact. Self-nomination is not permitted. The successful candidate is likely to have more than 10 years industrial experience and have made a significant contribution / impact within an industrial sector either by the creation of knowledge (e.g. evidenced by patents, development of industrial plant, etc.) or having shown excellence and a high degree of industrial leadership within their organization by making a significant impact upon the UK's social, environmental and economic well-being. The awardee will hold the respect of their colleagues and their contribution well-known in their particular field.

The 'Carbon in Industry' Award will consist of £500 prize and a certificate. We will expect the recipient, as a condition of the award, to receive their award at one of our meetings and to present an award lecture outlining their contribution to carbon in industry. Reasonable travel expenses will be paid by the BCG. Thus, the sixth award lecture is likely to occur in the last quarter of 2016.

The closing date for nominations will strictly be 4pm BST **1st September 2016**. No submissions after this date will be accepted.

Applications may be submitted *electronically* to the Chair of the British Carbon Group Awards Committee, Ms. Nassia Tzelepi, Research Fellow in Graphite Technology, NNL Central Laboratory, Sellafield, United Kingdom Nassia.Tzelepi@nnl.co.uk

Past Recipients

2015 Prof. Steve Tennison, MAST Carbon Ltd,
Nanoporous carbons-New and Emerging Industrial Applications

2011 Dr Steve Ragan, Global R&D director, Jacobi Carbons Ltd
Aspects of Activated Carbon and Household Water Filters

2010 Dr James Reed, Group Head at EDF Energy - Existing Nuclear
Graphite in Nuclear Energy

Roger Taylor awards 2016

The photo shows Dr Ardemis Boghassian, one of this year's Roger Taylor awardees receiving her certificate from Prof. Charlier

The other award was made to Dr Matthew Cole of the Engineering Department, University of Cambridge.

On the right is Dr. Antonio Correia, President of the Phantom Foundation which organised Graphene 2016, and on the left, Prof. Jean-Christopher Charlier, a co-organiser, from the Catholic University of Louvain.

2017 Ubbelohde lecturer

The British Carbon Group is pleased to announce that the Ubbelohde lecture for 2017 will be given by Prof. Eleanor Campbell FRS. The date and venue for the lecture have not yet been decided

RSC Faraday Division meeting

The Faraday Division of the RSC has announced the intention of holding a 2-day meeting of the Division where all the Groups that are affiliated to it, including of course the British Carbon Group, will be invited to take part. This is an initiative from the current President of the Division, Prof Eleanor Campbell and will be an innovation. The BGC committee has agreed in principle to support this meeting although arrangements are still at an early stage. We would probably host a session possibly jointly with another Group or Groups.

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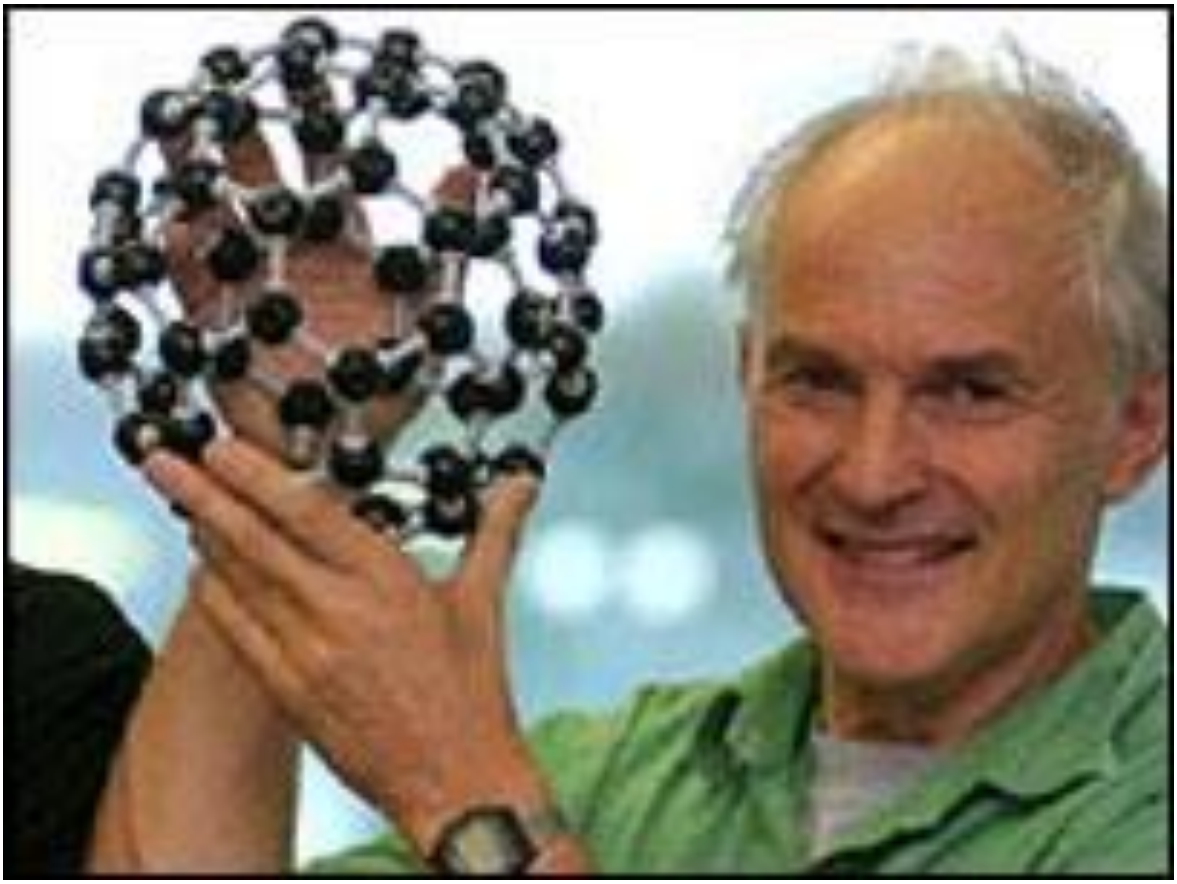

Sir Harry Kroto FRS, Nobel Laureate

1939-2016